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The end justifies the means – Sprayed sound-absorbing coating on non-acoustic materials

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ABSTRACT

There is a growing demand in the market for elegant but at the same time more sustainable acoustic solutions. To achieve good acoustic environments there are several ways to tackle the problem. Do we go to high-end luxury road, or could there be more affordable solutions with the same end results? And how to pull off the trick? In this study we present results from acoustical measurements taken in four different spaces of varying functionality where 10 mm thick acoustic coating has been installed directly on non-acoustical hard surfaces. The acoustic coating absorbs sound without the need of an acoustic base material underneath. When installed on existing surfaces, the carbon footprint of the building is reduced. The coating can be tinted to any color, and its texture can be customized from rough to smooth, thus architectural visual changes can be minimized. We demonstrate that the presented acoustic coating is a cost-efficient seamless acoustic solution that can be used to achieve excellent acoustic comfort, even though the thin layer sounds like insufficient. We demonstrate that coating can easily have larger surface area than traditional acoustic tiles, thus the required total absorption area is achieved with only 10 mm thick coating. The use of the acoustic coating, however, requires acoustic engineers, designers, and architects to rethink their acoustic plans with a more creative and sustainable mind.

1. INTRODUCTION

Traditional room acoustic solutions often involve suspended ceiling systems or glued sound-absorbing panels. In terms of aesthetics, these solutions might not be the preferred option. They may even be impractical or impossible to use in spaces where there are strict requirement to preserve the architectural visual design, such as in historical or architecturally protected buildings. Acoustic coatings offer an alternative solution to improve room acoustics while maintaining the visual appeal of spaces. These coatings can even seamlessly blend into the surfaces of spaces, sometimes becoming entirely unnoticeable.

Most of the acoustic coatings available on the market are non-sound absorbing materials. Instead, they are applied on top of acoustical panels. In this system, the function of the acoustic

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coating is hiding the seams between the underlying acoustic panels, while the acoustic panels provide the sound absorption properties. A well-known challenge in the use of non-sound absorbing coatings is that the thickness of the coating is critical to reach the full functionality of the acoustic solution. Too thick layer of coating will degrade the acoustical properties of the underlying acoustic panels and, consequently, the acoustical properties of the system. Too thin layer of coating will fail too entirely hide the seams between acoustic panels, thereby deteriorating the aesthetics of the solution. Generally, the critical thickness of non-sound absorbing coatings is 3-4 mm.

On the other hand, sound absorbing coatings offer several advantages compared to non-absorbing coatings. In first place, the thickness of the coating is not critical to achieve the full functionality of the acoustic solution. It must be thick enough to fully hide the seams between the underlying panels. In most cases, the minimum thickness required for this purpose is 5 mm. Too thick layer of coating will not degrade the acoustic properties of the underlying panels as sound waves will always go through the porous structure of the sound absorbing coating. Secondly, sound absorbing coatings can be utilized without the needs of employing underlying acoustical panels. They can be installed directly on non-acoustical hard surfaces and improve room acoustics. Their main constraint, however, is the limitation of their acoustic properties mainly due to their relatively small thickness. Nevertheless, the coating can easily have larger surface area than traditional acoustic tiles, thus the required total absorption area can be easily achieved by increasing the total surface area covered by the coating. Moreover, it can substitute other building materials like fillers and paints, providing sound absorption properties to surfaces primarily intended only for visual purposes.

In this study, we present four cases where biobased sound-absorbing acoustic coatings, installed directly on non-acoustic surfaces, have been used to improve the acoustic environment. The acoustically treated premises are an open-plan office space, a five-floor staircase, a restaurant, and a spa. High visual requirements were set in all of the cases for the sound absorbing structures. In practice, the acoustic treatment had to be unnoticeable. The acoustic of all the premises were evaluated via acoustical measurement of reverberation time, T_{30}, and speech clarity, C_{50}, taken before and after installation of the acoustic coating. The biobased sound absorbing coating used in all the premises is carbon negative. Thus, since the coating has been installed directly on existing surfaces, the carbon footprint of all the buildings has been reduced after installation of the coating.

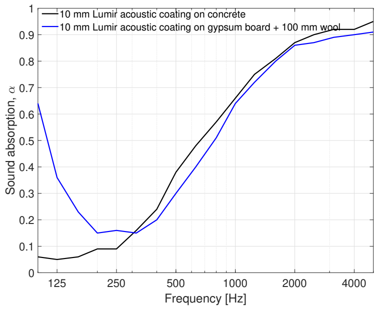
2. MATERIALS AND METHODS

2.1. Materials

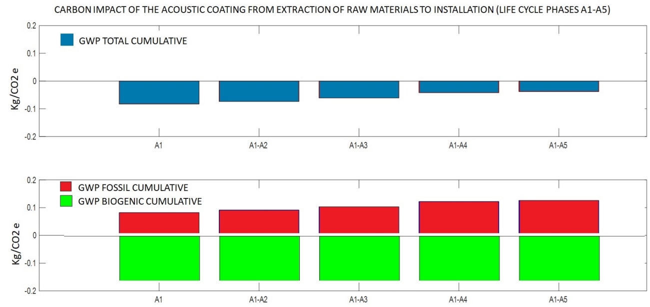
A sprayable biofibre-based sound absorbing coating manufactured by Lumir [1] was used as the acoustic solution for the acoustic design of all the premises presented in this study. In all the spaces, the coating was directly sprayed on existing non-acoustical hard surfaces. The thickness of the coating is 10 mm, the color and surface of the coating was tailored to meet client´s specifications, which generally requires minimizing visual changes to the architectural design of the premises. The coating can be sprayed almost on any surface. In most cases, installation of the coating involves first applying primer to the underlying surfaces to enhance adhesion of the coating. When sprayed on acoustical surfaces, such as mineral wool or perforated gypsum, the sound absorption coefficients of the acoustic solution improve at low and mid frequencies, leading to A-C sound absorption class depending on the underlying acoustical structure. The sound absorption coefficients of the 10 mm coating sprayed on two different non-acoustical hard surfaces are presented in Figure 1a:

- 10 mm biofibre-based acoustic coating sprayed on concrete. Sound absorption class D, α_w = 0.35 (MH).
- 10 mm biofibre-based acoustic coating sprayed on plain gypsum board with 100 mm mineral wool behind. Sound absorption class D, α_w = 0.35 (MH).

In addition to the acoustic properties, the biofibre-based sound absorbing coating acts as a carbon sink



(a) Sound absorption coefficients of biobased acoustic coating.



(b) Carbon impact of acoustic coating.

Figure 1: (a) Sound absorption coefficients of biofibre-based acoustic coating sprayed on different non-acoustic surface measured according to standard ISO 354 by an accredited laboratory. (b) Carbon impact of the biofibre-based acoustic coating according to results from environmental product declaration (EPD) report, including life cycle phases A1-A5, from extraction of raw materials to coating installation. The EPD has been conducted in accordance with EN 15804+A2 and ISO 14025.

during its operational life as it comprises approximately 80 weight percent (wt%) cellulosic fibres as its primary raw material. Under normal conditions, the operational life of the coating extends to several decades. Cellulose, the main structural component of natural fibers, consist about 49 wt% of carbon. Plants acquire this percent of carbon mainly as carbon dioxide (CO_2) from the atmosphere during their growth phase. The carbon dioxide is then processed into cellulose and other components via biosynthesis, with oxygen resulting as a side product. As a rule of thumb, carbon bound in 1 kg of cellulose, often referred as biogenic carbon, corresponds to roughly 1.5 kg of atmospheric carbon dioxide [2]. It can be estimated that the biofibres incorporated into the coating (80 wt%) capture approximately 1.2 kg of atmospheric CO_2/m^2.

According to Life Cycle Analysis (LCA), the coating is carbon-negative from life-cycle phase A1 to A5, including acquisition of raw materials, coating production and installation, see Figure 1b. Thus, the coating stores into its structure more carbon dioxide over its operational life than is released during its manufacturing and installation processes. The carbon footprint of building materials accounts for the carbon sequestration (biogenic carbon) and emissions associated to the building materials over their lifecycle. The carbon footprint of the biobased sound-absorbing coating is -0.038 kg CO_{2e} per kg of product, which, based on the density and thickness of the coating, implies that installation of the acoustic coating on existing surfaces results in a reduction of the carbon footprint of the building of around 46 g CO_{2e}/m^2.

2.2. Methodology

Four premises –an office, a staircase space, a restaurant, and a spa– have been acoustically treated with the use of 10 mm acoustic coating applied on non-acoustical hard surfaces. Assessment of acoustic parameters, including reverberation time (T_{30}) and speech clarity (C_{50}), was conducted in accordance with ISO 3382-1 (2009) both before and after implementing acoustic treatment (except for the open-plan office, where measurements where taken only after installation of acoustic coating). All the measurements were taken under unoccupied conditions. The software ARTA [3] was utilized to capture impulse responses via the inverse swept-sine technique [4]. The sound was emitted from an omnidirectional sound source, model LS02, and an omnidirectional 1/4-inch measurement microphone (Superlux ECM-999) was employed for recording. Moreover, the presented results represent averages from multiple measurements, with a minimum of two sound source and two receiver positions. Results on the effect of the acoustic coating on the carbon footprint of the acoustically treated spaces is also provided based on data from LCA.

(a) Open-plan office

(b) Staircases

(c) Restaurant

(d) Spa space

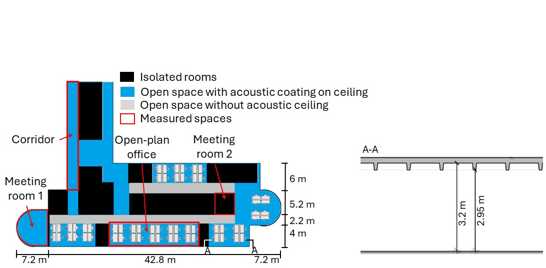
Figure 2: Images of the four spaces acoustically treated with 10 mm biobased acoustic coating sprayed on non-acoustical surfaces.

Figure 2 illustrates the four premises treated with the 10 mm acoustic coating. Layout and sections are shown in Figure 3. There were strict requirements for the acoustic treatment to avoid changes in the appearance of all the premises, taking into account the color and the structure of the surfaces. All the premises are briefly described below.

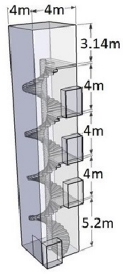
Office: the office was located in Porkkalankatu 3, Helsinki. The ceiling of the office was concrete vaulted slab, the structure can be seen in Figure 2a. The whole surface of the concrete vaulted slab on the ceiling was primed and sprayed with the 10 mm acoustic coating, including vertical and horizontal surfaces. Each of the concrete vaulted slab units added a total of 1.2 m^2 of acoustic coating on their vertical surfaces. Acoustical measurements were taken in a corridor, two meeting rooms, and an open-plan office. All the measured spaces had a thin sound absorbing carpet, upholstered chairs, and some of the workstations were equipped with 1.4 m high sound absorbing screens.

Staircases: the five-floor spiral staircase is located in the School of Business building at Aalto University. The acoustic design of the staircases is part of the artwork, Mare Tranquillitatis, by the artist group IC-98. The artwork aimed to create a zone of complete silence that serves as a place of tranquillity and confrontational encounter, as described by the authors. All the walls, the ground floor, and the ceiling are painted concrete. The stairs and landings were mosaic concrete, and the underneath of the stair-landing was plywood with an air cavity behind it. A concrete pile of 0.5 m of diameter was stranded in the middle of the spiral staircase from the ground floor up to a height of 18.5 m. All the walls and ceiling were treated with the 10 mm biobased acoustic coating directly on the primed concrete surface. The plywood in the underneath of stair-landings was exchanged with perforated gypsum boards sprayed with the 10 mm acoustic coating.

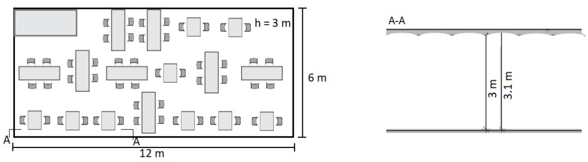
Restaurant: the space is located in Tehtaankatu 27-29, Helsinki. All the walls were brick surfaces, there was a thin carpet on the floor, and the ceiling was a vaulted brick structure as shown in Figure 2c. The vaulted brick ceiling was primed and acoustically treated with the 10 mm biobased acoustic coating.



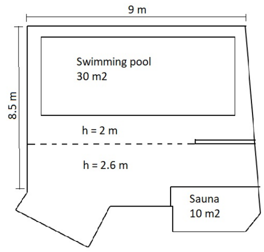
(a) Open-plan office



(b) Staircases



(c) Restaurant



(d) Spa

Figure 3: Layout and sections of the four spaces acoustically treated.

Spa: the spa space is part of a private house located in Helsinki. The spa has a 30 m^2 swimming pool, sauna and a space for showers. All the walls were hard surfaces. Wooden slat surface was found on one of the walls. The floor had tiles and the ceiling was suspended plain gypsum. The 10 mm acoustic coating was sprayed directly on the plain gypsum ceiling after spraying a layer of primer.

3. RESULTS AND DISCUSSION

Table 1 presents a summary of room volumes, floor surface area, total surface areas on ceilings and walls covered with acoustic coating, average reverberation time before and after installation of acoustic coating, as well as the impact of the acoustic coating on the carbon footprint of the building after installation.

3.1. Room acoustics

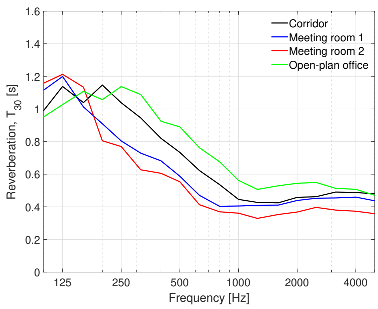
Figure 4 illustrates results from the acoustical measurements taken in the different premises presented in this study. It can be seen that the installed acoustic coating has led to significant improvement in reverberation time and speech clarity. Reverberation time has been decreased in all the spaces according to the sound absorption properties of the acoustic coating. The most significant reduction of reverberation time happens at frequencies above 500 Hz. However, the coating has also improved the room acoustics of all spaces at frequencies below 500 Hz. The influence of the acoustic coating on the mid and low frequencies depends on the acoustics of the space before installation as well as on the total surface area covered by the coating. Interestingly, reverberation time measurements in the spa, after installation of the acoustic coating, presents a strong flutter echo at around 3 kHz. In this space, furniture was minimal and sound absorbing surfaces were installed only on the ceiling, thus all the vertical surfaces were left to reflect sound. The flutter echo may arise between two walls, most probably between the walls in the shower area.

One of the main advantages of the acoustic coating compared to acoustic panels is that it can be installed on any surface without affecting the architectural design of the spaces. In addition, the visual outlook of the space is untouched, as the coating can be colored and the roughness of the

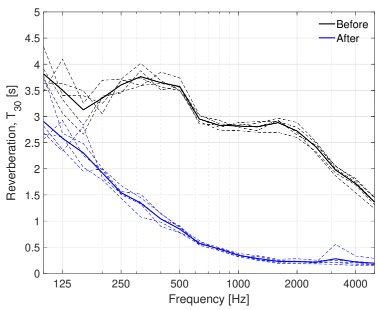
Table 1: summary of room volumes, floor surface area, total surface areas on ceilings and walls covered with acoustic coating, average reverberation time before and after installation of acoustic coating, as well as the impact of the acoustic coating on the carbon footprint of the building after installation.

	Volume [m^3]	Floor area[a] [m^2]	Acoustic coating on ceiling [m^2]	Acoustic coating on walls [m^2]	T_{30} before[b] [s]	T_{30} after[b] [s]	Bound atmospheric carbon on coating[c] [kg CO_{2e}]	Carbon footprint of installed coating[d] [kg CO_{2e}]
Open-plan office	377	74	120	0		0.7	210	-8.1
Corridor	95	30.1	48	0		0.6	58	-2.2
Meeting room 1	139	45	66	0		0.5	79	-3
Meeting room 2	81	26	44	0		0.5	53	-2
Staircases	331	-	63	188	2.8	0.7	301	-11.5
Restaurant	216	72	90	0	0.7	0.5	108	-4.1
Spa	190	80	80	0	2	1.1	96	-3.7

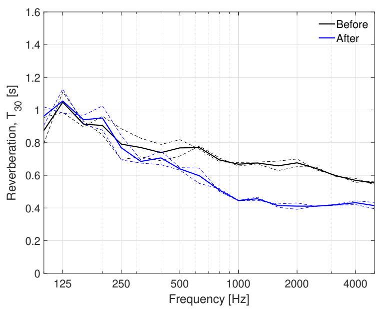
[a] Only the floor area below the ceiling areas covered with acoustic coating has been considered.
[b] Arithmetic average reverberation time across the third-octave-bands from 250 Hz to 4000 Hz.
[c] Biogenic carbon, the carbon content stored in the structure of the coating mainly due to the organic raw materials used for its production.
[d] Includes biogenic carbon and carbon emissions produced during the extraction of raw materials, coating manufacture, transportation and installation.



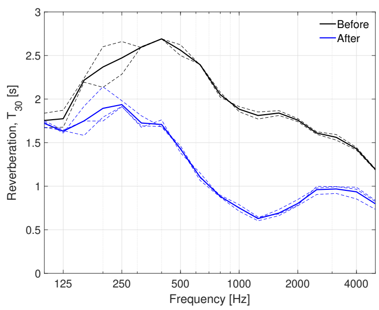
(a) Office, T_{30}



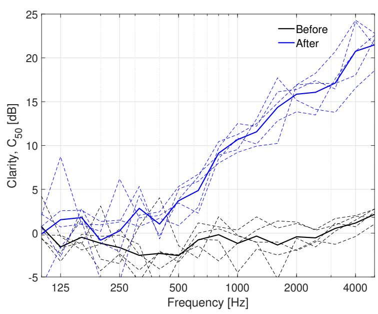
(b) Staircases, T_{30}



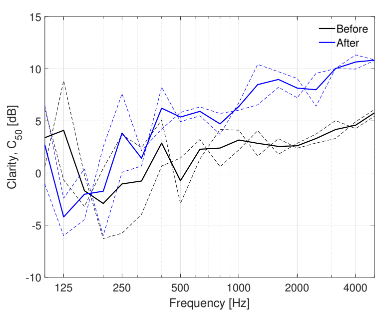
(c) Restaurant, T_{30}



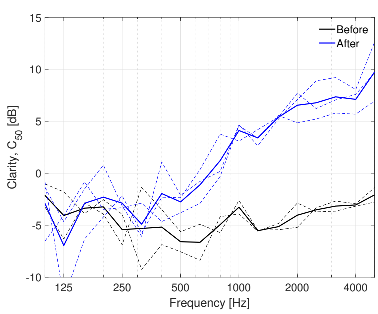
(d) Spa, T_{30}



(e) Staircases, C_{50}



(f) Restaurant, C_{50}



(g) Spa, C_{50}

Figure 4: Reverberation time, T_{30}, and speech clarity, C_{50} measured in the acoustically treated premises after installation of biobased acoustic coating on non-acoustical hard surfaces.

finished surface adjusted. Therefore, the coating can easily cover larger surface areas than traditional acoustic tiles. Despite the coating having poorer absorption at frequencies lower than 500 Hz, by increasing the total surface area of the absorptive material, it can achieve the same absorption area as more efficient absorbers.

For example, in the open-plan office, the ceiling area covered with the acoustic coating is 120 m^2. The maximum ceiling area that could be covered using acoustic tiles would be 74 m^2, as acoustic tiles could be installed only on horizontal surfaces of the concrete vaulted slabs to preserve the aesthetics of the ceiling. Figure 5 illustrates the total absorption area achieved with the 10 mm acoustic coating versus the total absorption area that could be achieved using A-, B-, or C-class acoustic tiles. It can be seen that at 500 Hz, the total absorption area achieved by the acoustic coating is equal to that achieved by the acoustic solution based on C-class acoustic tiles. Above 700 Hz, the total absorption area is considerable greater for the acoustic coating compared to the acoustic tiles-based solutions.

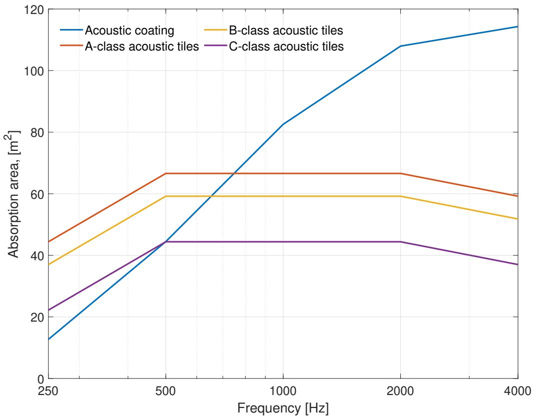


Figure 5: Total absorption area calculated for 10 mm biobased sound absorbing coating installed on 120 m^2 versus absorption area for acoustic tiles installed on 74 m^2.

Speech has been reported as the most disturbing sound source in open-plan offices [5]. In such spaces, it is beneficial to maximise the area of sound absorbing surfaces to avoid spreading of speech noise between workstations. Thus, maximising sound absorbing area for frequencies above 500 Hz would reduce the radius of distraction, and more importantly, it would decrease speech intelligibility between workstations as speech intelligibility would be high only at very short distances. This is not usually a concern as employees in an open-plan office are generally distributed in teams working in common subjects. If additional absorption area is required at mid and low frequencies, it could be easily increased by spraying the acoustic coating on other surfaces such as on the walls. Due to the toughness of the coating, it is suitable to be installed on walls. This addition of acoustic coating on walls would not alter the visual aesthetic of the space while it significantly aid in preventing the propagation of noise.

Expanding the application area of the acoustic coating may raise concerns about the costs associated with the acoustic treatment. However, among seamless acoustic solutions utilizing acoustic coatings, spraying a 10 mm acoustic coating on existing surfaces emerges as the most cost-effective option as it eliminates material costs associated with underlying acoustic materials. In comparison, the material costs for 1 m^2 of a seamless acoustic solution involving acoustic coating sprayed on top of acoustic underlying material equal those of 1.5 m^2 of acoustic coating directly sprayed on existing surfaces. Additionally, installing the coating without using underlying acoustic materials significantly reduces installation time, resulting in lower overall installation costs. Moreover, the use of tinted acoustic coating could substitute the use of other building materials such as fillers and paints, thus leading to further savings.

3.2. Environmental viewpoint

The carbon impact of the acoustic coating on all the spaces is reported in Table 1. The biobased acoustic coating installed in all the spaces bound approximately 1.2 kg CO_{2e}/m^2. The carbon footprint of each of the premises, including biogenic and carbon emissions, was reduced by 48 g of CO_{2e}/m^2. In individual spaces, the decrease of the carbon footprint by a biofibre-based acoustic coating might seem insignificant, especially in the presented case studies, as the rooms are quite small. However, the carbon impact of the coating is much more significant when one considers bigger buildings, as well as all the building materials that can be omitted due to the installation of the acoustic coating, such as paints and fillers. Furthermore, compared to other traditional acoustic solutions, such as glass wool or perforated gypsum, the use of glass wool would increase the carbon footprint of the building by 3.1 kg of CO_{2e}/kg, whereas the use of perforated gypsum would increase the carbon footprint of the building by 1.9 kg of CO_{2e}/kg [2]. For example, taken the open-plan office case, installing 74 m^2 of 20 mm glass wool of density 90 kg/m^3 would increase the carbon footprint of the building by 133.2 kg of CO_{2e}. This value, compared to the reduction in the carbon footprint of the building achieved with the installation of the biobased sound absorbing acoustic coating on 120 m^2, -8.1 CO_{2e}, demonstrates the capability of the acoustic coating as one of the most sustainable seamless acoustic solution.

4. CONCLUSIONS

This study presents the use of a biobased sound absorbing coating, directly sprayed to existing non-acoustic surfaces, as the primary measure in the acoustic treatment of any space where the main objective of the acoustic design is to mitigate propagation of speech noise, such as shopping malls, large reception areas, corridors, restaurants, and open-plan offices. The 10 mm acoustic coating has its own limitations, especially at frequencies below 500 Hz. At such frequencies, if greater absorption is needed, acoustic designers count with several other tools to absorb sound, such as acoustic screens, carpets, or some sound-diffusing elements such as shelves. On the other hand, the acoustic coating permits the treatment of larger surface areas, thereby augmenting the total absorption area below 500 Hz. This, in turn, leads to an enhanced absorption at a wider frequency range. Moreover, the acoustic coating could substitute other building materials like fillers and paints, providing sound absorption properties to surfaces primarily intended only for visual purposes.

The presented case studies proved that acoustical treatment can be done while respecting the architectural visual aesthetics and even reducing the carbon footprint of the buildings. The increase use of such carbon-negative building materials is indispensable towards an economy with net-zero greenhouse gas emissions, where buildings will reverse their role in the fight against climate change.

ACKNOWLEDGEMENTS

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